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THE EFFECTS OF LASER
ENGRAVING ON THE ESTIMATED
SERVICE LIFE OF PRERECORDED COMPACT
DISCS (CD-ROM)

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Prepared for the Library of Congress by
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*Preservation Directorate
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No. 9604 - Gibson, Gerald D., with Carole Zimmermann and Terry Erb. ***Cylinder Audio Recordings: An Annotated Bibliography.*** 1996.

No. 9705 - Nugent, William R. ***Digitizing Library Collections for Preservation and Archiving: A Handbook for Curators.*** 1997.

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No. 9807 - Reilly, James M., Nishimura, Douglas W., and Daniel Burge. ***Condition Survey of Motion Picture Holdings in the Library of Congress: Evaluation of Storage Environments for Motion Picture Collections.*** 1998.

No. 9808 - Baker, James M. and George E. Klechefske. ***Risk Analysis Study for a Representative Magnetic Tape Collection.*** 1998.

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No. 9 - Gibson, Gerald D. ***Preservation of Magnetic Media: A Bibliography. Part I.*** 2001.

No. 10 - Shahani, Chandru J., Youket, Michele H., and Norman Weberg. ***Compact Disc Service Life: An investigation of the Estimated Service Life of Prerecorded Compact Discs (CD-ROM) Held at the Library of Congress.*** 2005.

No. 11 - Shahani, Chandru J., Youket, Michele H., and Norman Weberg. ***The Effects of Laser Engraving on the Estimated Service Life of Prerecorded Compact Discs (CD-ROM).*** 2005.

A Comparison of Estimated Service Life of Prerecorded Compact Discs with and without Laser Engraving

Conclusion:

Laser engraved identification as described below produces neither a statistical nor a practical difference in the estimated service life of CD-ROMs.

Objective:

The objective of this report was to compare the Life Expectancy (LE) of information stored on prerecorded compact discs as a function of laser engraving. For the purposes of this Report, a prerecorded compact disc is considered to be a CD-ROM or a CD-Audio. It does not include recordable CD's (CD-R), rewritable CD's (CD-RW), or DVD's.

Background:

Published Life Expectancy estimates of CD-ROM's typically include a population of discs stressed and tested in the "As Manufactured" state. Modification of the disc, including after market labeling, must be done at the user's risk. The only recommended labeling was that which the manufacturer printed on the disc. Customarily the manufacturer uses a screen printed artwork followed by application of protective coatings and final ink curing. Such operations allow production of many replicates with indistinguishable appearance.

User application of labels to such discs introduces possibilities of producing short term and / or long term harm. Such effects could be brought about by:

- Unintentionally removing one or all of the protective coatings if an adhesive coated label were removed or repositioned.
- Upsetting the disc dynamic balance of the disc, especially at high rotational speeds if the labels result in an asymmetric mass on the disc.
- Fracturing the reflector surface during the writing operation.

Solvent based inks, such as those used in felt tipped markers were considered to have potentially harmful effects from the ink solvent. With all of the ink compositions available and all of the CD coating variables, it was not deemed practical to qualify any such markers for CD labeling. Even if once qualified, either the marker or CD manufacturer could change critical parameters of their products.

The Library of Congress has begun research into indelibly marking discs held in the disc collection. This report compares the effects of engraving an identifying mark on a specific surface of the compact disc. The area used for such engraving is approximately 26 mm in diameter and is well within the inner stacking ring (32 to 36 mm diameter) of the CD. The stacking ring is a raised portion of the disc which is molded into the polycarbonate substrate. The purpose of the stacking ring is to prevent disc to disc contact during manufacture and shipping in a stacked mode. This area:

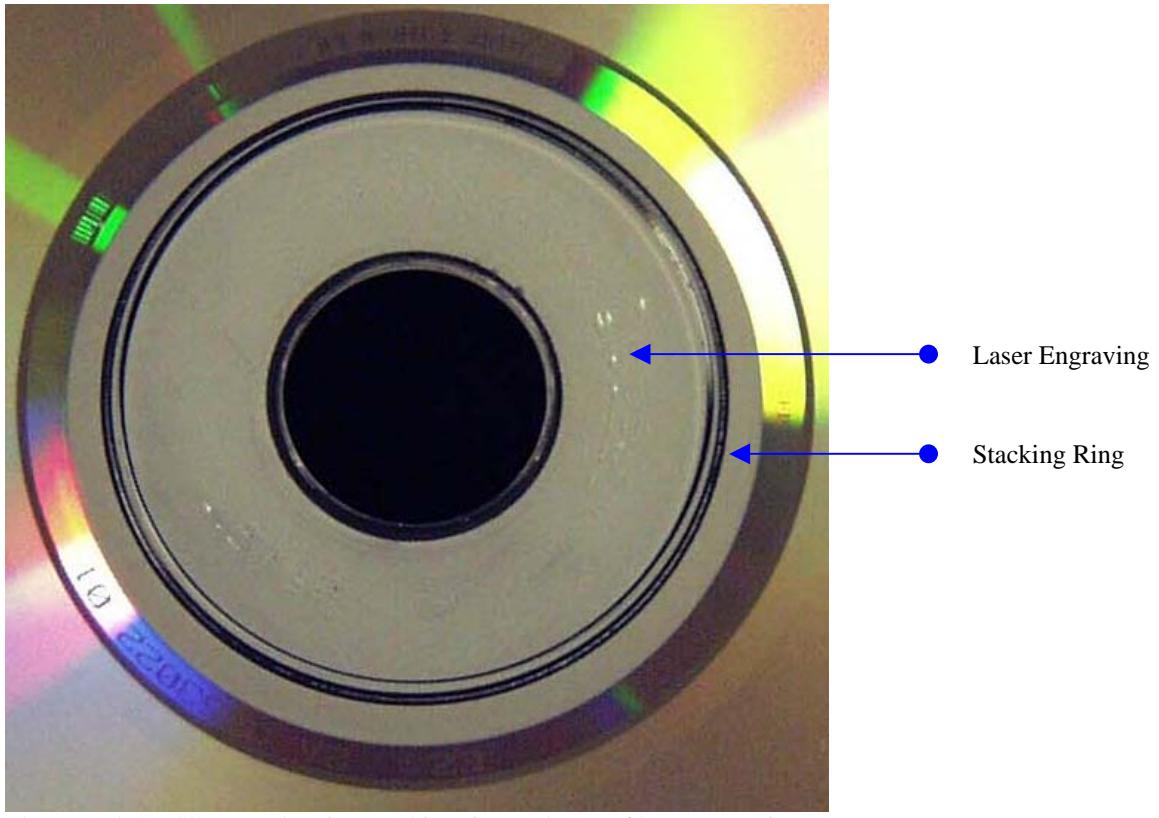
- Contains no functional information.
- Usually is not coated with screen printed artwork
- Very seldom, if ever, is covered with protective coatings such as lacquer
- Is close to the center of rotation, thereby minimizing any possible effect of dynamic unbalance
- Is not coated with any functioning reflector

The effects of temperature and relative humidity on the service life of CD-ROM discs have been modeled. The results of this modeling were reported in “Service Life of Prerecorded Compact Discs” of August 16th, 2004. Pairs of test specimens for that study had been selected randomly representing the disc population of the Library of Congress. One of each pair of discs was laser engraved within the inner stacking ring (Type C). The other disc of the pair were not engraved (Type D). Thus Type C media was “Experimental” and Type D media was “Control”. The engraving represents a marking used to identify the disc as Library of Congress property. Photograph 1 below shows the construction a typical compact disc (CD-ROM). The arrow indicates the typical stacking ring



Photograph 1: Typical CD-ROM disc construction

Photograph 2 below shows a close up of the center portion of this same disc. The radius of the laser engraving is approximately midway between the center hole and the stacking ring. It may be noted that the actual engraving is barely visible and therefore rather non-intrusive to any of the disc artwork.



Photograph 2: Close up showing stacking ring and area of laser engraving.

Comparison of Engraved and Non-Engraved CD ROM Life Expectancies.

In the August 16th 2004 report referenced above, all of the discs were treated as one population. Block Error Rate was measured following known time increments of exposure to accelerated temperature and relative humidity conditions. The time to reach end-of-life (EOL) was calculated as the time required to reach a BLER of 220 sec⁻¹. The distribution of the EOLs within a given accelerating condition was determined. The fit of the experimental data was compared to four common distributions including Weibull, Lognormal, Normal and Exponential. A lognormal failure time relationship was determined to best describe the distribution of measured or estimated life expectancies for all of the accelerating conditions.

Lognormal Distribution:

The lognormal cumulative failure equation is expressed below:

$$F(t) = \frac{1}{\sqrt{2\pi}} \int_0^t \frac{1}{\sigma l} e^{-\frac{1}{2}\left(\frac{\log(x) - \mu l}{\sigma l}\right)^2} dx$$

Where σl = log standard deviation

μl = (log mean)

x = specimen failure time

The log mean for each temperature / relative humidity was regressed to fit an Eyring acceleration model.

$$t(50\%) = Ae^{-\Delta H / kT_e} (B) RH$$

From this data, the time for 50% failure could be calculated at any given temperature (T) and relative humidity (RH). Using 25 °C and 50 % RH as the user condition, the relative acceleration at each of the elevated temperature and RH conditions could be determined. By applying the acceleration factor to each of the individual disc EOL, an estimated EOL, normalized to 25 °C / 50% RH was determined for each disc. All of the discs, both Type C and Type D were treated as one population. The combined normalized data was used obtain the final parameters for the lognormal distribution at user conditions. The life expectancy was expressed as the portion of discs surviving, with a given confidence level, when stored at a prescribed temperature and relative humidity.

Attachment 1 (BLER as a function of stress and exposure time) of The August report is included at the end of this report as a convenience to the reader.

For the purposes of this report, the discs population was separated into two distinct populations; Type C and Type D. The same End of Life estimates were used for this report as were used for the August 16th report. The only difference is that the Type C disc EOLs and the Type D EOLs were analyzed as separate independent populations.

Data Analysis:

From the data obtained in the August 2004 report, the calculated time to reach End-of-Life for each was sorted by treatment type (Type C or Type D). Data for the Type C discs were separated from the data for the Type D Discs. The results of this operation are shown below in Table 1.

Table 1: Summary of Normalized End-of-Life (Years) by Disc Type

Disc ID	Years to EOL	Disc ID	Years to EOL
1C	6399.40	1D	6399.40
2C	6399.40	2D	51.66
3C	281.28	3D	153.56
5C	114.71	5D	68.15
6C	943.20	6D	1118.94
7C	6399.40	7D	673.62
8C	94.84	8D	91.91
9C	25.50	9D	33.01
10C	21.81	10D	21.84
11C	4172.85	11D	1781.69
12C	190.62	12D	2494.37
13C	190.62	13D	186.84
14C	2564.43	14D	1429.87
16C	3106.28	16D	666.25
19C	6317.66	17D	4211.77
20C	260.65	19D	347.18
21C	102.73	20D	255.08
23C	583.89	21D	107.40
24C	152.08	22D	6341.01
25C	358.12	23D	641.11
27C	126.26	24D	169.78
28C	150.37	25D	750.12

29C	61.49		27D	108.02
30C	91.91		28D	586.01
33C	65.42		29D	54.26
34C	1042.09		33D	108.36
35C	3052.60		34D	740.76
37C	12744.13		35D	721.43
38C	400.65		37D	12744.13
39C	702.43		38D	733.33
40C	59.61		39D	901.07
41C	424.74		40D	1175.54
42C	606.91		41D	404.61
44C	106.76		42D	856.10
45C	597.58		44D	102.62
46C	6824.03		46D	1124.65
47C	47.21		47D	64.32
48C	104.80		48D	73.85
50C	15.13		50D	15.75
51C	1734.55		51D	301.66
52C	50.58		52D	40.93
53C	236.48		53D	807.30
55C	21.38		54D	6798.66
56C	53.41		55D	21.38
57C	42.36		56D	37.65
58C	3481.78		57D	43.72
59C	2729.61		58D	3481.78
60C	1942.48		59D	1362.27
71-C	132.06		60D	100.49
72-C	305.59		71-D	163.32
73-C	129.26		72-D	2728.93
75-C	1089.94		73-D	130.84
77-C	376.55		75-D	1050.33
78-C	13329.39		77-D	362.99
80-C	126.78		78-D	6654.00
			80-D	117.77

The probability of each disc within a type (Type C or Type D) to reach its end-of-life (EOL) was compared to four standard distributions. These distributions included the Weibull, Lognormal, Exponential and Normal distributions. These four were considered to be the most common mathematical estimates of a population based on a sample treated to accelerated stress condition. Figure 1 below shows graphically, the fit obtained for each of the four distributions evaluated.

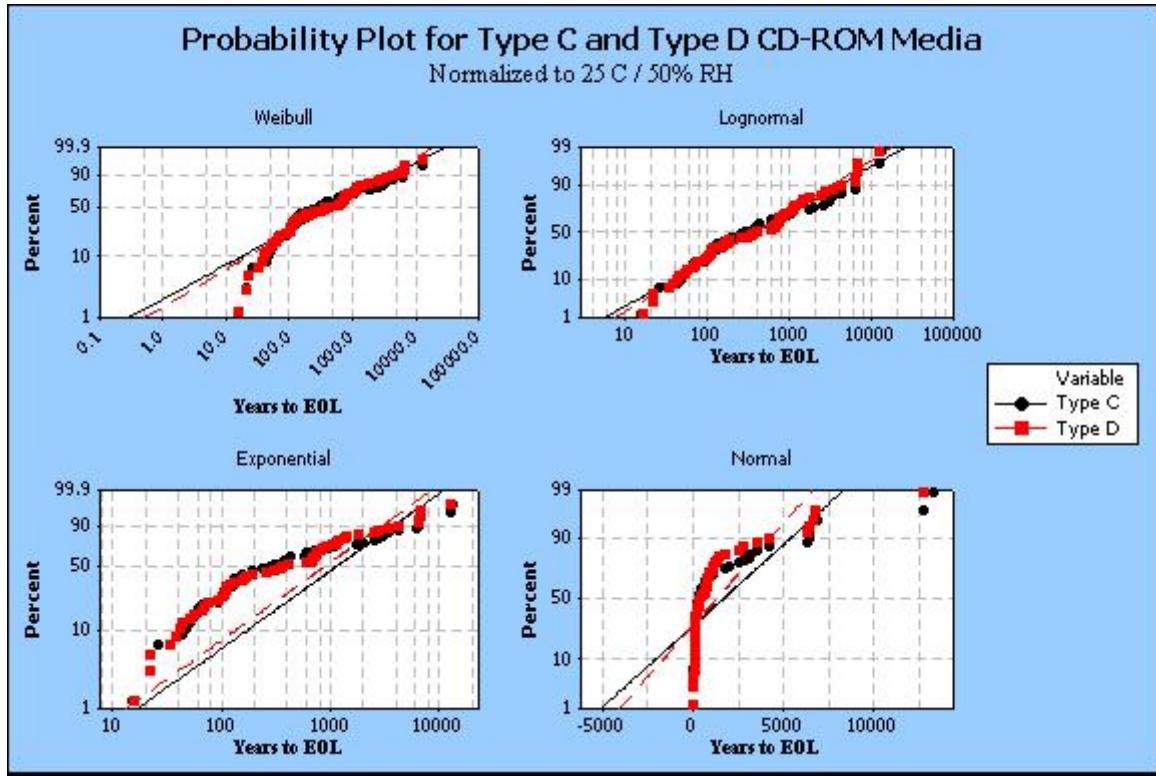


Figure 1: Probability plots comparing Type C and Type D CD-ROM discs to various distributions

It may be seen that in each of the four distributions, the Type C discs are not different than the Type D discs. In addition it may be seen that, of the four distributions, the Lognormal distribution is the best fit for both Type C and Type D discs.

Figure 2 below is a more detailed graph showing the fit of the individual discs to the Lognormal distribution equation.

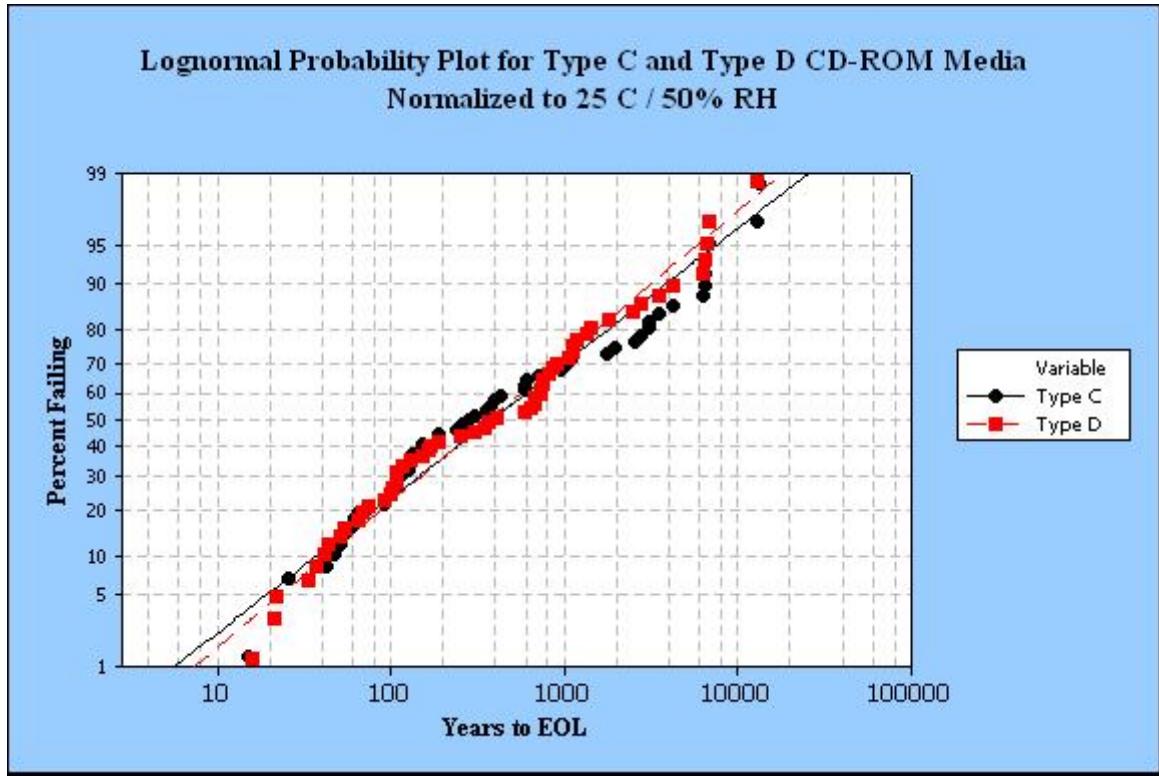


Figure 2: Probability plots comparing Type C and Type D CD-ROM discs to the Lognormal distributions

It may again be seen that there is an excellent fit of both Type C and Type D data to the lognormal distribution and that there is neither a practical nor a statistical difference between the two sets of discs.

For comparison, the lognormal probability plot reproduced from the August 16th 2004 report is shown as Figure 3 below. Figure 3 shows the results of a lognormal distribution using both Type C and Type D data combined into one population.

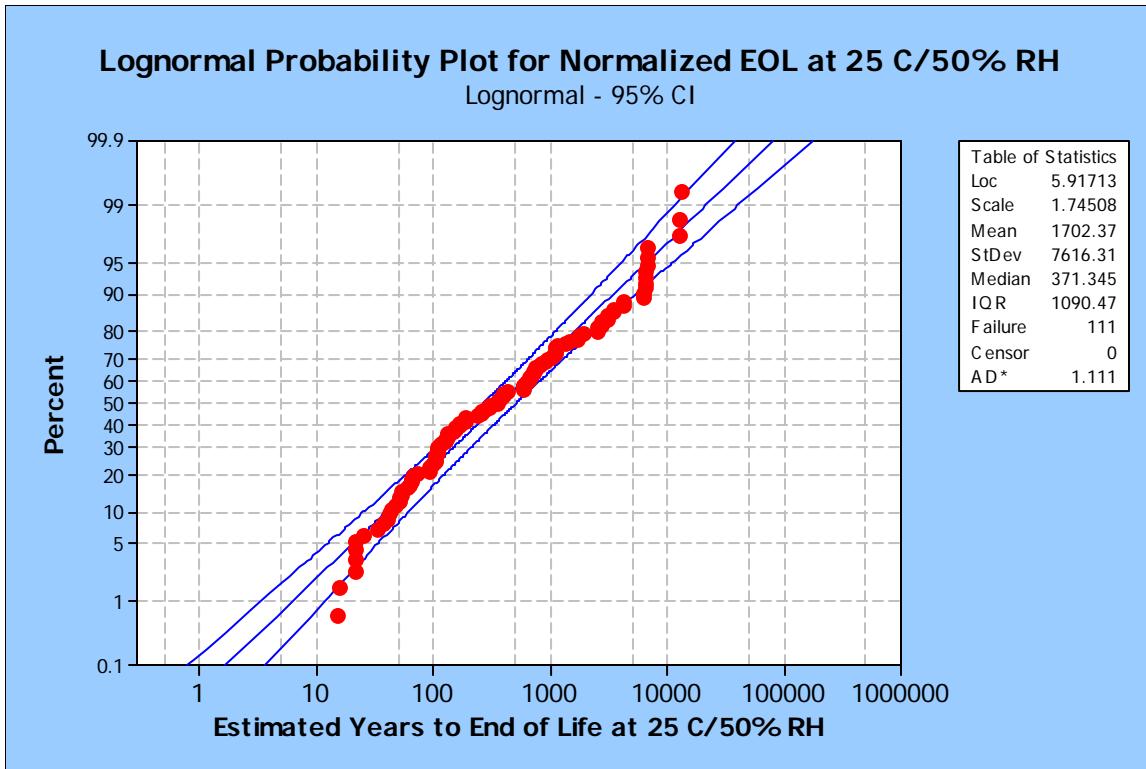


Figure 3: Lognormal Probability Plot for combined Type C and Type D discs from August 2004 Report

Figure 2 above shows the probability of an individual disc, or percent of the total population, that are expected to fail as a function of time at 25 °C and 50% RH. The Survival Plot, as a function of time at 25 °C and 50% RH is shown on Figure 4 below. For the purpose of clarity and detail, a linear scale is used for both time and cumulative percent surviving.

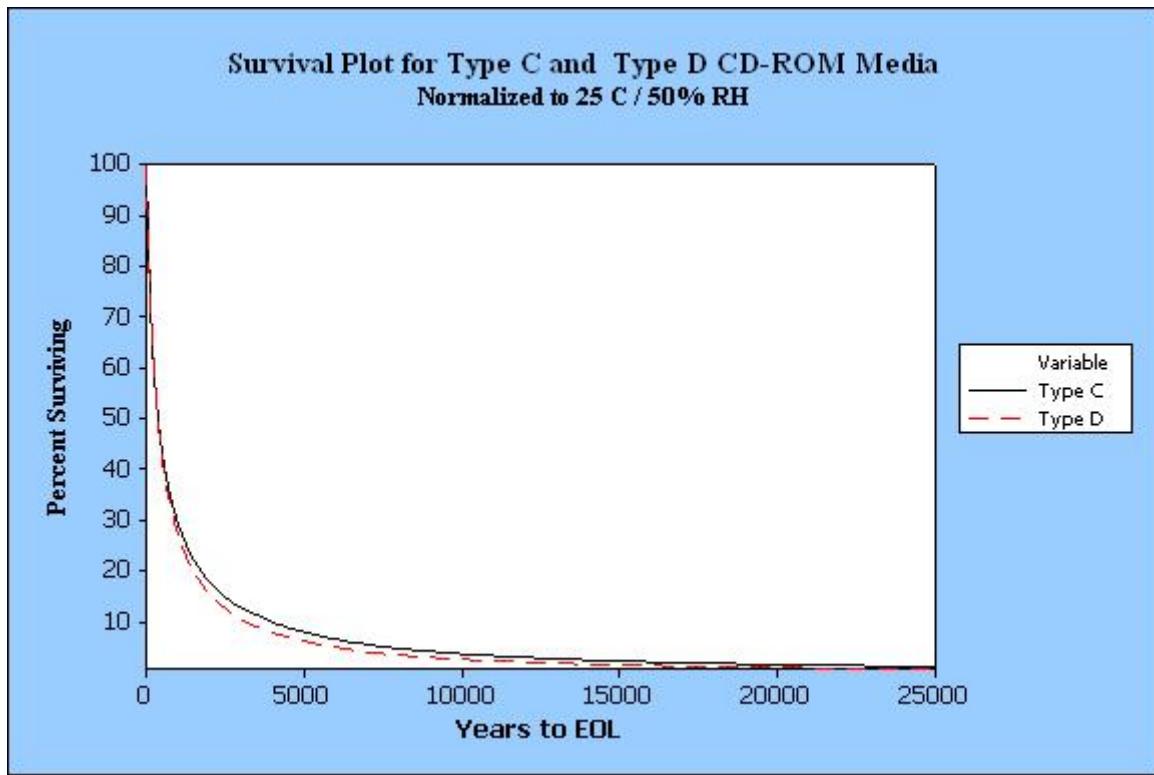


Figure 4: Survival plots comparing Type C and Type D CD-ROM discs to the Lognormal distributions

Figure 5 below is the same graph as Figure 4 but with a scale chosen to more precisely indicate the percent surviving during the first 250 years.

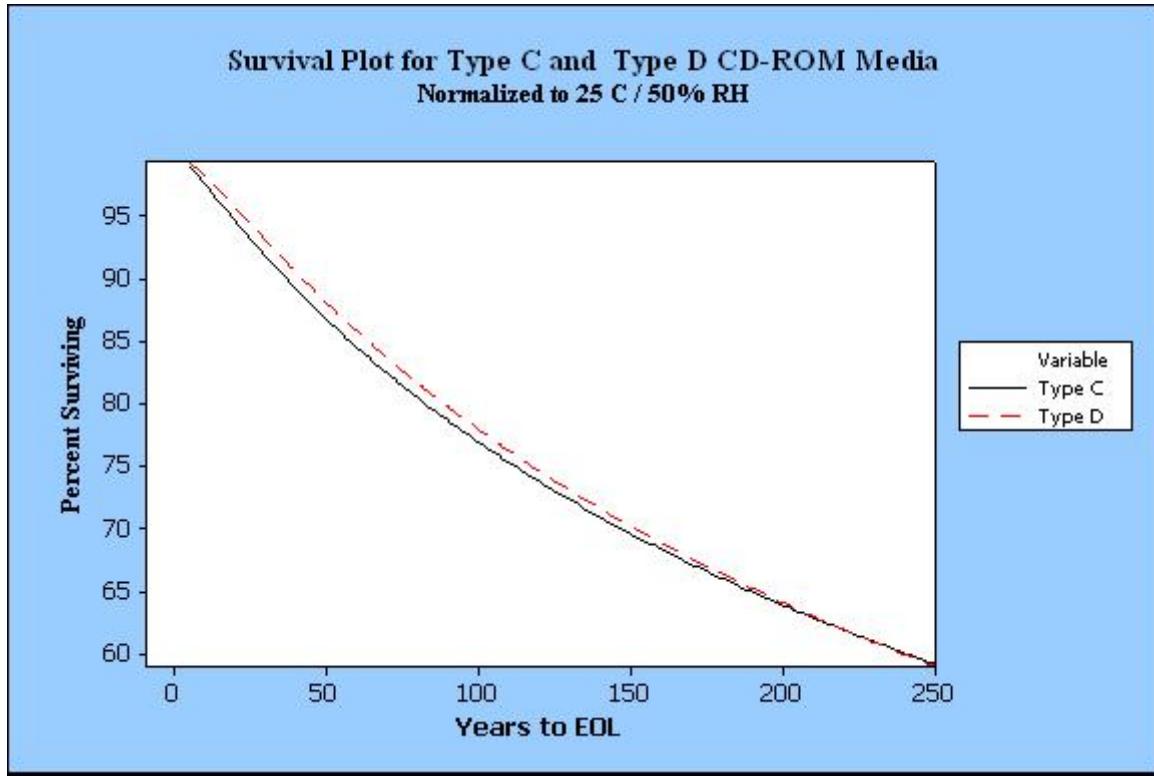


Figure 5: Cumulative Failure plots comparing Type C and Type D CD-ROM discs to the Lognormal distributions – Expanded scale.

Table 2 below shows the percent of the collection population that is estimated to fail, as a function of some selected times (Years) at 25 °C / 50 % Relative Humidity.

Table 2: Percent of CD-ROMs Surviving, by Type, as a function of selected times

Time (Years)	Percent Surviving Type C	Percent Surviving Type D
1	99.95	99.97
2	99.81	99.90
5	99.06	99.47
10	97.77	98.39
20	94.80	95.82
25	93.35	94.49
50	86.86	88.19
100	76.93	77.99
200	63.83	64.02
250	59.12	58.95

It may be seen that there is no appreciable difference, either statistically or practically, between the Type C and Type D failure rates.

Attachment 1

Block error Rate (10 sec average) for each disc

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG71C	1	1	0	22
EG71D	1	1	0	14
EG72C	1	1	0	4
EG72D	1	1	0	4
EG73C	1	1	0	10
EG73D	1	1	0	14
EG74C	1	1	0	4
EG74D	1	1	0	4
EG75C	1	1	0	0
EG75D	1	1	0	0
EG76C	1	1	0	4
EG76D	1	1	0	4
EG77C	1	1	0	0
EG77D	1	1	0	2
EG78C	1	1	0	6
EG78D	1	1	0	6
EG79C	1	1	0	2
EG79D	1	1	0	10
EG80C	1	1	0	6
EG80D	1	1	0	6
EG71C	2	1	1000	36
EG71D	2	1	1000	16
EG72C	2	1	1000	16
EG72D	2	1	1000	4
EG73C	2	1	1000	122
EG73D	2	1	1000	124
EG74C	2	1	1000	236
EG74D	2	1	1000	206
EG75C	2	1	1000	2
EG75D	2	1	1000	0
EG76C	2	1	1000	500
EG76D	2	1	1000	500
EG77C	2	1	1000	24
EG77D	2	1	1000	24
EG78C	2	1	1000	8
EG78D	2	1	1000	10
EG79C	2	1	1000	
EG79D	2	1	1000	
EG80C	2	1	1000	20
EG80D	2	1	1000	10

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG71C	3	1	1500	128
EG71D	3	1	1500	80
EG72C	3	1	1500	52
EG72D	3	1	1500	6
EG73C	3	1	1500	182
EG73D	4	1	1500	180
EG74C	3	1	1500	496
EG74D	4	1	1500	490
EG75C	4	1	1500	8
EG75D	3	1	1500	6
EG76C	3	1	1500	500
EG76D	3	1	1500	500
EG77C	3	1	1500	34
EG77D	3	1	1500	34
EG78C	3	1	1500	8
EG78D	3	1	1500	10
EG80C	3	1	1500	84
EG80D	3	1	1500	132
EG71C	4	1	2000	266
EG71D	4	1	2000	226
EG72C	4	1	2000	106
EG72D	4	1	2000	16
EG73C	4	1	2000	206
EG73D	5	1	2000	204
EG74C	5	1	2000	500
EG74D	5	1	2000	500
EG75C	5	1	2000	30
EG75D	4	1	2000	32
EG76C	4	1	2000	500
EG76D	4	1	2000	500
EG77C	4	1	2000	86
EG77D	4	1	2000	92
EG78C	4	1	2000	8
EG78D	4	1	2000	10
EG80C	4	1	2000	312
EG80D	4	1	2000	318
EG61C	1	2	0	4
EG61D	1	2	0	6
EG62C	1	2	0	26
EG62D	1	2	0	12
EG63C	1	2	0	44
EG63D	1	2	0	24

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG64C	1	2	0	8
EG64D	1	2	0	6
EG65C	1	2	0	4
EG65D	1	2	0	4
EG66c	1	2	0	2
EG66D	1	2	0	0
EG67C	1	2	0	4
EG67D	1	2	0	4
EG68C	1	2	0	12
EG68D	1	2	0	10
EG69C	1	2	0	4
EG70C	1	2	0	4
EG70D	1	2	0	4
EG69D	1	2	0	500
EG61C	2	2	500	500
EG61D	2	2	500	500
EG62C	2	2	500	28
EG62D	2	2	500	14
EG63C	2	2	500	140
EG63D	2	2	500	28
EG64C	2	2	500	222
EG64D	2	2	500	238
EG65C	2	2	500	188
EG65D	2	2	500	8
EG66C	2	2	500	6
EG66D	2	2	500	6
EG67C	2	2	500	30
EG67D	2	2	500	30
EG68C	2	2	500	500
EG68D	2	2	500	500
EG69C	2	2	500	482
EG69D	2	2	500	484
EG70C	2	2	500	4
EG70D	2	2	500	4
EG61C	3	2	1000	500
EG61D	3	2	1000	500
EG62C	3	2	1000	28
EG62D	3	2	1000	24
EG63C	3	2	1000	230
EG63D	3	2	1000	34
EG64C	3	2	1000	244
EG64D	3	2	1000	232
EG65C	3	2	1000	446
EG65D	3	2	1000	116

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG66C	3	2	1000	28
EG66D	3	2	1000	8
EG67C	3	2	1000	42
EG67D	3	2	1000	46
EG68C	3	2	1000	500
EG68D	3	2	1000	500
EG70C	3	2	1000	4
EG70D	3	2	1000	4
EG61C	4	2	1500	500
EG61D	4	2	1500	500
EG62C	4	2	1500	30
EG62D	4	2	1500	50
EG63C	4	2	1500	312
EG63D	4	2	1500	76
EG64C	4	2	1500	252
EG64D	4	2	1500	262
EG65C	4	2	1500	500
EG65D	4	2	1500	480
EG66C	4	2	1500	182
EG66D	5	2	1500	24
EG67C	4	2	1500	48
EG67D	4	2	1500	48
EG68C	4	2	1500	500
EG68D	4	2	1500	500
EG70C	4	2	1500	22
EG70D	4	2	1500	42
EG61C	5	2	2000	500
EG61D	5	2	2000	500
EG62C	5	2	2000	60
EG62D	5	2	2000	98
EG63C	5	2	2000	500
EG63D	5	2	2000	136
EG64C	5	2	2000	258
EG64D	5	2	2000	248
EG65C	5	2	2000	500
EG65D	5	2	2000	500
EG66C	5	2	2000	394
EG66D	6	2	2000	94
EG67C	5	2	2000	54
EG67D	5	2	2000	62
EG68C	5	2	2000	500
EG68D	5	2	2000	500
EG70C	5	2	2000	130
EG70D	5	2	2000	220
EG46C	1	3	0	4
EG46D	1	3	0	6

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG47C	1	3	0	0
EG47D	1	3	0	0
EG48C	1	3	0	2
EG48D	1	3	0	40
EG49C	1	3	0	10
EG49D	1	3	0	10
EG4C	1	3	0	4
EG4D	1	3	0	4
EG50C	1	3	0	8
EG50D	1	3	0	8
EG51C	1	3	0	2
EG51D	1	3	0	8
EG52C	1	3	0	4
EG52D	1	3	0	4
EG53C	1	3	0	2
EG53D	1	3	0	2
EG54C	1	3	0	6
EG54D	1	3	0	6
EG55C	1	3	0	6
EG55D	1	3	0	6
EG56C	1	3	0	4
EG56D	1	3	0	4
EG57C	1	3	0	2
EG57D	1	3	0	2
EG58C	1	3	0	0
EG58D	1	3	0	0
EG59C	1	3	0	4
EG59D	1	3	0	4
EG5C	1	3	0	6
EG5D	1	3	0	8
EG60C	1	3	0	4
EG60D	1	3	0	2
EG46C	2	3	500	6
EG46D	4	3	500	10
EG47C	2	3	500	74
EG47D	2	3	500	74
EG48C	2	3	500	52
EG48D	2	3	500	78
EG49C	2	3	500	10
EG49D	2	3	500	10
EG4C	2	3	500	4
EG4D	2	3	500	4
EG50C	2	3	500	136
EG50D	2	3	500	112
EG51C	2	3	500	2
EG51D	2	3	500	8

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG52C	2	3	500	6
EG52D	2	3	500	6
EG53C	2	3	500	10
EG53D	2	3	500	8
EG54C	2	3	500	6
EG54D	2	3	500	6
EG55C	2	3	500	14
EG55D	2	3	500	10
EG56C	2	3	500	36
EG56D	2	3	500	28
EG57C	2	3	500	74
EG57D	2	3	500	68
EG58C	2	3	500	2
EG58D	2	3	500	2
EG59C	2	3	500	6
EG59D	2	3	500	8
EG5C	2	3	500	6
EG5D	2	3	500	10
EG60C	2	3	500	8
EG60D	2	3	500	2
EG46C	3	3	1000	6
EG46D	5	3	1000	14
EG47C	3	3	1000	118
EG47D	3	3	1000	118
EG48C	3	3	1000	84
EG48D	3	3	1000	126
EG49C	3	3	1000	10
EG49D	3	3	1000	10
EG4C	3	3	1000	4
EG4D	3	3	1000	4
EG50C	3	3	1000	500
EG50D	3	3	1000	500
EG51C	3	3	1000	4
EG51D	3	3	1000	12
EG52C	3	3	1000	22
EG52D	3	3	1000	30
EG53C	3	3	1000	22
EG53D	3	3	1000	12
EG54C	3	3	1000	6
EG54D	3	3	1000	6
EG55C	3	3	1000	312
EG55D	3	3	1000	256
EG56C	3	3	1000	76
EG56D	3	3	1000	168
EG57C	3	3	1000	176
EG57D	3	3	1000	172

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG58C	3	3	1000	2
EG58D	3	3	1000	2
EG59C	3	3	1000	8
EG59D	3	3	1000	10
EG5C	3	3	1000	44
EG5D	3	3	1000	64
EG60C	3	3	1000	10
EG60D	3	3	1000	4
EG49C	5	3	1332	10
EG50C	5	3	1332	500
EG55D	5	3	1332	500
EG46C	5	3	1500	6
EG46D	7	3	1500	14
EG47D	5	3	1500	130
EG48C	5	3	1500	96
EG48D	5	3	1500	146
EG49D	5	3	1500	10
EG4C	4	3	1500	4
EG4D	4	3	1500	4
EG50D	5	3	1500	500
EG51D	5	3	1500	24
EG52C	5	3	1500	138
EG52D	5	3	1500	182
EG53C	5	3	1500	36
EG53D	5	3	1500	14
EG54C	5	3	1500	6
EG54D	5	3	1500	6
EG55C	5	3	1500	500
EG56C	5	3	1500	158
EG56D	5	3	1500	260
EG57C	5	3	1500	214
EG57D	5	3	1500	210
EG58C	5	3	1500	2
EG58D	5	3	1500	2
EG59C	6	3	1500	8
EG59D	5	3	1500	12
EG5C	4	3	1500	76
EG5D	4	3	1500	124
EG60C	6	3	1500	10
EG60D	5	3	1500	32
EG46C	6	3	2000	6
EG46D	8	3	2000	16
EG47D	6	3	2000	170
EG48C	6	3	2000	102
EG48D	6	3	2000	152

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG49C	6	3	2000	10
EG49D	6	3	2000	10
EG4C	5	3	2000	4
EG4D	5	3	2000	4
EG50C	6	3	2000	500
EG50D	6	3	2000	500
EG51D	6	3	2000	46
EG52C	6	3	2000	270
EG52D	6	3	2000	348
EG53C	6	3	2000	48
EG53D	6	3	2000	16
EG54C	6	3	2000	6
EG54D	6	3	2000	8
EG55C	6	3	2000	500
EG55D	6	3	2000	500
EG56C	6	3	2000	218
EG56D	6	3	2000	270
EG57C	6	3	2000	232
EG57D	6	3	2000	224
EG58C	6	3	2000	4
EG58D	6	3	2000	4
EG59C	7	3	2000	8
EG59D	6	3	2000	12
EG5C	5	3	2000	84
EG5D	5	3	2000	146
EG60C	7	3	2000	10
EG60D	6	3	2000	142
EG31C	1	4	0	0
EG31D	1	4	0	0
EG32C	1	4	0	6
EG32D	1	4	0	6
EG33C	1	4	0	2
EG33D	1	4	0	2
EG34C	1	4	0	2
EG34D	1	4	0	2
EG35C	1	4	0	16
EG35D	1	4	0	4
EG36C	1	4	0	4
EG36D	1	4	0	4
EG37C	1	4	0	0
EG37D	1	4	0	0
EG38C	1	4	0	2
EG38D	1	4	0	4
EG39C	1	4	0	0
EG39D	1	4	0	0

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG40C	1	4	0	6
EG40D	1	4	0	8
EG41C	1	4	0	4
EG41D	1	4	0	4
EG42C	1	4	0	12
EG42D	1	4	0	16
EG43C	1	4	0	0
EG43D	1	4	0	0
EG44C	1	4	0	2
EG44D	1	4	0	2
EG45C	1	4	0	4
EG45D	1	4	0	4
EG31C	2	4	750	0
EG31D	2	4	750	0
EG32C	2	4	750	448
EG32D	2	4	750	412
EG33C	2	4	750	8
EG33D	2	4	750	12
EG34C	2	4	750	10
EG34D	2	4	750	8
EG35C	2	4	750	6
EG35D	2	4	750	16
EG36C	2	4	750	12
EG36D	2	4	750	6
EG37C	2	4	750	0
EG37D	2	4	750	0
EG38C	2	4	750	6
EG38D	2	4	750	4
EG39C	2	4	750	8
EG39D	2	4	750	8
EG40C	2	4	750	16
EG40D	2	4	750	6
EG41C	2	4	750	16
EG41D	2	4	750	16
EG42C	2	4	750	34
EG42D	2	4	750	20
EG43C	2	4	750	2
EG43D	2	4	750	2
EG44C	2	4	750	36
EG44D	2	4	750	38
EG45C	2	4	750	6
EG31C	4	4	1500	246
EG31D	3	4	1500	250
EG32C	3	4	1500	500
EG32D	3	4	1500	500

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG33C	3	4	1500	38
EG33D	3	4	1500	16
EG34C	3	4	1500	14
EG34D	3	4	1500	16
EG35C	3	4	1500	18
EG35D	3	4	1500	6
EG36C	3	4	1500	388
EG36D	3	4	1500	410
EG37C	3	4	1500	0
EG37D	3	4	1500	0
EG38C	3	4	1500	4
EG38D	3	4	1500	6
EG39C	3	4	1500	18
EG39D	3	4	1500	14
EG40C	3	4	1500	10
EG40D	4	4	1500	18
EG41C	3	4	1500	38
EG41D	3	4	1500	38
EG42C	3	4	1500	26
EG42D	3	4	1500	42
EG43C	3	4	1500	230
EG43D	3	4	1500	176
EG44C	3	4	1500	108
EG44D	3	4	1500	128
EG45C	3	4	1500	6
EG31C	6	4	2250	500
EG31D	5	4	2250	500
EG32C	6	4	2250	500
EG32D	5	4	2250	500
EG33C	5	4	2250	258
EG33D	5	4	2250	44
EG34C	5	4	2250	18
EG34D	5	4	2250	24
EG35C	5	4	2250	18
EG35D	5	4	2250	10
EG36C	5	4	2250	500
EG36D	5	4	2250	500
EG37C	5	4	2250	0
EG37D	5	4	2250	0
EG38C	5	4	2250	10
EG38D	5	4	2250	10
EG39C	5	4	2250	24
EG39D	5	4	2250	20
EG40C	5	4	2250	242
EG40D	6	4	2250	20

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG41C	5	4	2250	44
EG41D	5	4	2250	46
EG42C	5	4	2250	28
EG42D	5	4	2250	46
EG43C	5	4	2250	500
EG43D	5	4	2250	500
EG44C	5	4	2250	160
EG44D	5	4	2250	164
EG45C	5	4	2250	16
EG31C	7	4	3000	500
EG31D	6	4	3000	500
EG32C	7	4	3000	500
EG32D	6	4	3000	500
EG33C	6	4	3000	378
EG33D	6	4	3000	268
EG34C	6	4	3000	22
EG34D	6	4	3000	28
EG35C	6	4	3000	18
EG35D	6	4	3000	42
EG36C	6	4	3000	500
EG36D	6	4	3000	500
EG37C	6	4	3000	2
EG37D	6	4	3000	2
EG38C	6	4	3000	66
EG38D	6	4	3000	36
EG39C	6	4	3000	28
EG39D	6	4	3000	22
EG40C	6	4	3000	484
EG40D	7	4	3000	22
EG41C	6	4	3000	48
EG41D	7	4	3000	50
EG42C	6	4	3000	54
EG42D	6	4	3000	30
EG43C	6	4	3000	500
EG43D	7	4	3000	500
EG44C	7	4	3000	176
EG44D	6	4	3000	180
EG45C	6	4	3000	42
EG45D	2	4	Aged 70 C/85% RH; soak 1; cleaned; 04.28.03	4
EG45D	3	4	Aged 70 C/85% RH; soak 2; cleaned; 07.31.03	8
EG10C	1	5	0	4
EG10D	1	5	0	4

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG11C	1	5	0	6
EG11D	1	5	0	6
EG12C	1	5	0	6
EG12D	1	5	0	6
EG13C	1	5	0	4
EG13D	1	5	0	6
EG14C	1	5	0	0
EG14D	1	5	0	0
EG15C	1	5	0	2
EG15D	1	5	0	2
EG16C	1	5	0	8
EG16D	1	5	0	6
EG17C	1	5	0	6
EG17D	1	5	0	4
EG18C	1	5	0	4
EG18D	1	5	0	4
EG19C	1	5	0	4
EG19D	1	5	0	4
EG1C	1	5	0	0
EG1D	1	5	0	0
EG20C	1	5	0	4
EG20D	1	5	0	4
EG21C	1	5	0	4
EG21D	1	5	0	4
EG22C	1	5	0	4
EG22D	1	5	0	2
EG23C	1	5	0	2
EG23D	1	5	0	2
EG24C	1	5	0	2
EG24D	1	5	0	2
EG25C	1	5	0	2
EG25D	1	5	0	2
EG26C	1	5	0	8
EG26D	1	5	0	8
EG27C	1	5	0	4
EG27D	1	5	0	2
EG28C	1	5	0	2
EG28D	1	5	0	2
EG29C	1	5	0	10
EG29D	1	5	0	30
EG2C	1	5	0	4
EG2D	1	5	0	4
EG30C	1	5	0	18
EG30D	1	5	0	40
EG3C	1	5	0	2
EG3D	1	5	0	2

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG6C	1	5	0	10
EG6D	1	5	0	10
EG7C	1	5	0	0
EG7D	1	5	0	0
EG8C	1	5	0	2
EG8D	1	5	0	2
EG9C	1	5	0	12
EG9D	1	5	0	14
EG10C	2	5	1000	24
EG10D	2	5	1000	20
EG11C	2	5	1000	6
EG11D	2	5	1000	6
EG12C	2	5	1000	8
EG12D	2	5	1000	8
EG13C	2	5	1000	6
EG13D	2	5	1000	6
EG14C	2	5	1000	2
EG14D	2	5	1000	2
EG15C	2	5	1000	2
EG15D	2	5	1000	2
EG16C	2	5	1000	8
EG16D	2	5	1000	8
EG17C	2	5	1000	6
EG17D	2	5	1000	4
EG18C	2	5	1000	4
EG18D	2	5	1000	4
EG19C	2	5	1000	4
EG19D	2	5	1000	4
EG1C	2	5	1000	2
EG1D	2	5	1000	2
EG20C	2	5	1000	4
EG20D	2	5	1000	4
EG21C	2	5	1000	8
EG21D	2	5	1000	8
EG22C	2	5	1000	4
EG22D	2	5	1000	4
EG23C	2	5	1000	4
EG23D	2	5	1000	4
EG24C	2	5	1000	2
EG24D	2	5	1000	2
EG25C	2	5	1000	4
EG25D	2	5	1000	4
EG26C	2	5	1000	8
EG26D	2	5	1000	8
EG27C	2	5	1000	12
EG27D	2	5	1000	10

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG28C	2	5	1000	2
EG28D	2	5	1000	2
EG29C	2	5	1000	10
EG29D	2	5	1000	28
EG2C	2	5	1000	6
EG2D	2	5	1000	6
EG30C	2	5	1000	22
EG30D	2	5	1000	40
EG3C	2	5	1000	8
EG3D	2	5	1000	6
EG6C	2	5	1000	12
EG6D	2	5	1000	10
EG7C	2	5	1000	2
EG7D	2	5	1000	4
EG8C	2	5	1000	2
EG8D	2	5	1000	2
EG9C	2	5	1000	14
EG9D	2	5	1000	14
EG10C	3	5	2000	208
EG10D	3	5	2000	194
EG11C	3	5	2000	6
EG11D	3	5	2000	6
EG12C	3	5	2000	10
EG12D	3	5	2000	8
EG13C	3	5	2000	20
EG13D	3	5	2000	22
EG14C	3	5	2000	2
EG14D	3	5	2000	2
EG15C	3	5	2000	2
EG15D	3	5	2000	2
EG16C	3	5	2000	8
EG16D	3	5	2000	6
EG17C	3	5	2000	6
EG17D	3	5	2000	4
EG18C	3	5	2000	4
EG18D	3	5	2000	4
EG19C	3	5	2000	4
EG19D	3	5	2000	12
EG1C	3	5	2000	2
EG1D	3	5	2000	2
EG20C	3	5	2000	8
EG20D	3	5	2000	10
EG21C	3	5	2000	42
EG21D	3	5	2000	42
EG22C	3	5	2000	4
EG22D	3	5	2000	4

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG23C	3	5	2000	6
EG23D	3	5	2000	6
EG24C	3	5	2000	14
EG24D	3	5	2000	16
EG25C	3	5	2000	12
EG25D	3	5	2000	10
EG26C	3	5	2000	8
EG26D	3	5	2000	8
EG27C	3	5	2000	48
EG27D	3	5	2000	52
EG28C	3	5	2000	16
EG28D	3	5	2000	6
EG29C	3	5	2000	10
EG29D	3	5	2000	28
EG2C	3	5	2000	28
EG2D	3	5	2000	32
EG30C	3	5	2000	36
EG30D	3	5	2000	40
EG3C	4	5	2000	12
EG3D	3	5	2000	12
EG6C	3	5	2000	16
EG6D	3	5	2000	14
EG7C	3	5	2000	2
EG7D	3	5	2000	10
EG8C	3	5	2000	14
EG8D	3	5	2000	12
EG9C	3	5	2000	104
EG9D	3	5	2000	54
EG10C	4	5	3000	468
EG10D	4	5	3000	480
EG11C	4	5	3000	8
EG11D	4	5	3000	6
EG12C	4	5	3000	10
EG12D	4	5	3000	10
EG13C	4	5	3000	42
EG13D	4	5	3000	44
EG14C	4	5	3000	4
EG14D	4	5	3000	4
EG15C	4	5	3000	2
EG15D	4	5	3000	2
EG16C	4	5	3000	8
EG16D	4	5	3000	10
EG17C	4	5	3000	6
EG17D	4	5	3000	6
EG18C	4	5	3000	4
EG18D	4	5	3000	4

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG19C	4	5	3000	4
EG19D	4	5	3000	22
EG1C	4	5	3000	2
EG1D	4	5	3000	2
EG20C	4	5	3000	24
EG20D	4	5	3000	26
EG21C	4	5	3000	80
EG21D	4	5	3000	76
EG22C	4	5	3000	4
EG22D	4	5	3000	4
EG23C	4	5	3000	12
EG23D	4	5	3000	12
EG24C	4	5	3000	42
EG24D	4	5	3000	42
EG25C	4	5	3000	20
EG25D	4	5	3000	10
EG26C	4	5	3000	8
EG26D	4	5	3000	8
EG27C	4	5	3000	70
EG27D	4	5	3000	78
EG28C	4	5	3000	40
EG28D	4	5	3000	10
EG29C	4	5	3000	20
EG29D	4	5	3000	44
EG2C	4	5	3000	100
EG2D	4	5	3000	130
EG30C	4	5	3000	80
EG30D	4	5	3000	40
EG3C	5	5	3000	20
EG3D	4	5	3000	36
EG6C	4	5	3000	18
EG6D	4	5	3000	16
EG7C	4	5	3000	2
EG7D	4	5	3000	14
EG8C	4	5	3000	50
EG8D	4	5	3000	46
EG9C	4	5	3000	358
EG9D	4	5	3000	226
EG10C	5	5	4000	490
EG10D	5	5	4000	496
EG11C	5	5	4000	8
EG11D	5	5	4000	6
EG12C	5	5	4000	12
EG12D	5	5	4000	10
EG13C	5	5	4000	54
EG13D	5	5	4000	56

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG14C	5	5	4000	4
EG14D	5	5	4000	8
EG15C	5	5	4000	2
EG15D	5	5	4000	2
EG16C	5	5	4000	12
EG16D	5	5	4000	24
EG17C	5	5	4000	6
EG17D	5	5	4000	6
EG18C	5	5	4000	4
EG18D	5	5	4000	4
EG19C	5	5	4000	6
EG19D	5	5	4000	32
EG1C	5	5	4000	2
EG1D	5	5	4000	2
EG20C	5	5	4000	44
EG20D	5	5	4000	44
EG21C	5	5	4000	96
EG21D	5	5	4000	92
EG22C	5	5	4000	4
EG22D	5	5	4000	4
EG23C	5	5	4000	20
EG23D	5	5	4000	18
EG24C	5	5	4000	70
EG24D	5	5	4000	60
EG25C	5	5	4000	30
EG25D	5	5	4000	16
EG26C	5	5	4000	8
EG26D	5	5	4000	8
EG27C	5	5	4000	76
EG27D	5	5	4000	88
EG28C	5	5	4000	72
EG28D	5	5	4000	20
EG29C	5	5	4000	250
EG29D	5	5	4000	282
EG2C	5	5	4000	176
EG2D	5	5	4000	230
EG30C	5	5	4000	128
EG30D	5	5	4000	38
EG3C	6	5	4000	42
EG3D	5	5	4000	74
EG6C	5	5	4000	20
EG6D	5	5	4000	18
EG7C	5	5	4000	2
EG7D	5	5	4000	14
EG8C	5	5	4000	126
EG8D	5	5	4000	134

OrdName	TestNum	Cell	Time (Hours)	BLE_avg
EG9C	5	5	4000	492
EG9D	5	5	4000	392

Attachment 2

Estimated time for End-of-Life at 25 Deg. C / 50 % RH by Disc Type (C or D)

Disc ID	Intercept	Slope	EOL(HRS)	EOL(yrs)	Acc. Fact	Norm(EOL)
1C	0.8	0.0004	548000	62.56	102.297	6399.40
2C	0.8	0.0004	548000	62.56	102.297	6399.40
3C	-1.6	0.0092	24087	2.75	102.297	281.28
5C	-2	0.0226	9823	1.12	102.297	114.71
6C	10	0.0026	80769	9.22	102.297	943.20
7C	0.8	0.0004	548000	62.56	102.297	6399.40
8C	-20.4	0.0296	8122	0.93	102.297	94.84
9C	-64.8	0.1304	2184	0.25	102.297	25.50
10C	-44.4	0.1416	1867	0.21	102.297	21.81
11C	5.6	0.0006	357333	40.79	102.297	4172.85
12C	-2	0.0136	16324	1.86	102.297	190.62
13C	-2	0.0136	16324	1.86	102.297	190.62
14C	0.4	0.001	219600	25.07	102.297	2564.43
16C	7.2	0.0008	266000	30.37	102.297	3106.28
19C	3.6	0.0004	541000	61.76	102.297	6317.66
20C	-3.2	0.01	22320	2.55	102.297	260.65
21C	-5.2	0.0256	8797	1.00	102.297	102.73
23C	0	0.0044	50000	5.71	102.297	583.89
24C	-9.2	0.0176	13023	1.49	102.297	152.08
25C	-0.8	0.0072	30667	3.50	102.297	358.12
27C	1.6	0.0202	10812	1.23	102.297	126.26
28C	-9.2	0.0178	12876	1.47	102.297	150.37
29C	-38	0.049	5265	0.60	102.297	61.49
30C	1.2	0.0278	7871	0.90	102.297	91.91
33C	-63.6	0.1336	2123	0.24	269.979	65.42
34C	3.6	0.0064	33813	3.86	269.979	1042.09
35C	12	0.0021	99048	11.31	269.979	3052.60
37C	-0.4	0.000533	413508	47.20	269.979	12744.13
38C	-8.8	0.0176	13000	1.48	269.979	400.65
39C	1.2	0.0096	22792	2.60	269.979	702.43
40C	-84.8	0.1576	1934	0.22	269.979	59.61
41C	6.8	0.01547	13782	1.57	269.979	424.74
42C	15.2	0.0104	19692	2.25	269.979	606.91
44C	2	0.06293	3464	0.40	269.979	106.76
45C	-2.4	0.01147	19390	2.21	269.979	597.58
46C	4.8	0.0008	269000	30.71	222.225	6824.03
47C	6	0.115	1861	0.21	222.225	47.21
48C	18.4	0.0488	4131	0.47	222.225	104.80
50C	59.2	0.2696	596	0.07	222.225	15.13
51C	1.2	0.0032	68375	7.81	222.225	1734.55
52C	-44.8	0.1328	1994	0.23	222.225	50.58
53C	0	0.0236	9322	1.06	222.225	236.48

55C	-28.4	0.2948	843	0.10	222.225	21.38
56C	-11.6	0.11	2105	0.24	222.225	53.41
57C	19.6	0.12	1670	0.19	222.225	42.36
58C	0.4	0.0016	137250	15.67	222.225	3481.78
59C	4.8	0.002	107600	12.28	222.225	2729.61
60C	5.6	0.0028	76571	8.74	222.225	1942.48
71C	-16.3429	0.115	2055	0.23	562.904	132.06
72C	-9.88571	0.04834	4756	0.54	562.904	305.59
73C	15.8286	0.1015	2012	0.23	562.904	129.26
75C	-4.91429	0.01326	16962	1.94	562.904	1089.94
77C	-7.71429	0.03886	5860	0.67	562.904	376.55
78C	6.34286	0.00103	207434	23.68	562.904	13329.39
80C	-46.3429	0.135	1973	0.23	562.904	126.78
1D	0.8	0.0004	548000	62.56	102.297	6399.40
2D	-34.8	0.0576	4424	0.50	102.297	51.66
3D	-8.8	0.0174	13149	1.50	102.297	153.56
5D	-7.6	0.039	5836	0.67	102.297	68.15
6D	9.2	0.0022	95818	10.94	102.297	1118.94
7D	0.8	0.0038	57684	6.58	102.297	673.62
8D	-22.4	0.0308	7870	0.90	102.297	91.91
9D	-53.6	0.0968	2826	0.32	102.297	33.01
10D	-50	0.1444	1870	0.21	102.297	21.84
11D	6.4	0.0014	152571	17.42	102.297	1781.69
12D	6.4	0.001	213600	24.38	102.297	2494.37
13D	-0.8	0.0138	16000	1.83	102.297	186.84
14D	-0.4	0.0018	122444	13.98	102.297	1429.87
16D	3.2	0.0038	57053	6.51	102.297	666.25
17D	3.6	0.0006	360667	41.17	102.297	4211.77
19D	0	0.0074	29730	3.39	102.297	347.18
20D	-2.8	0.0102	21843	2.49	102.297	255.08
21D	-4.4	0.0244	9197	1.05	102.297	107.40
22D	2.8	0.0004	543000	61.99	102.297	6341.01
23D	0.4	0.004	54900	6.27	102.297	641.11
24D	-6.8	0.0156	14538	1.66	102.297	169.78
25D	1.6	0.0034	64235	7.33	102.297	750.12
27D	-2	0.024	9250	1.06	102.297	108.02
28D	-0.8	0.0044	50182	5.73	102.297	586.01
29D	-21.6	0.052	4646	0.53	102.297	54.26
33D	-44.4	0.0752	3516	0.40	269.979	108.36
34D	2	0.00907	24035	2.74	269.979	740.76
35D	1.6	0.00933	23408	2.67	269.979	721.43
37D	-0.4	0.000533	413508	47.20	269.979	12744.13
38D	-2	0.00933	23794	2.72	269.979	733.33
39D	1.6	0.00747	29237	3.34	269.979	901.07

40D	6.4	0.0056	38143	4.35	269.979	1175.54
41D	6.4	0.01627	13128	1.50	269.979	404.61
42D	20	0.0072	27778	3.17	269.979	856.10
44D	6	0.06427	3330	0.38	269.979	102.62
46D	7.2	0.0048	44333	5.06	222.225	1124.65
47D	19.2	0.0792	2535	0.29	222.225	64.32
48D	50	0.0584	2911	0.33	222.225	73.85
50D	49.6	0.2744	621	0.07	222.225	15.75
51D	1.2	0.0184	11891	1.36	222.225	301.66
52D	-58.8	0.1728	1613	0.18	222.225	40.93
53D	3.6	0.0068	31824	3.63	222.225	807.30
54D	5.6	0.0008	268000	30.59	222.225	6798.66
55D	-28.4	0.2948	843	0.10	222.225	21.38
56D	-6.8	0.1528	1484	0.17	222.225	37.65
57D	18	0.1172	1724	0.20	222.225	43.72
58D	0.4	0.0016	137250	15.67	222.225	3481.78
59D	5.2	0.004	53700	6.13	222.225	1362.27
60D	-25.6	0.062	3961	0.45	222.225	100.49
71D	-24	0.096	2542	0.29	562.904	163.32
72D	1.71429	0.00514	42468	4.85	562.904	2728.93
73D	20.0571	0.0982	2036	0.23	562.904	130.84
75D	-6.05714	0.01383	16345	1.87	562.904	1050.33
77D	-7.25714	0.04023	5649	0.64	562.904	362.99
78D	6.68571	0.00206	103551	11.82	562.904	6654.00
80D	-47.9429	0.1462	1833	0.21	562.904	117.77